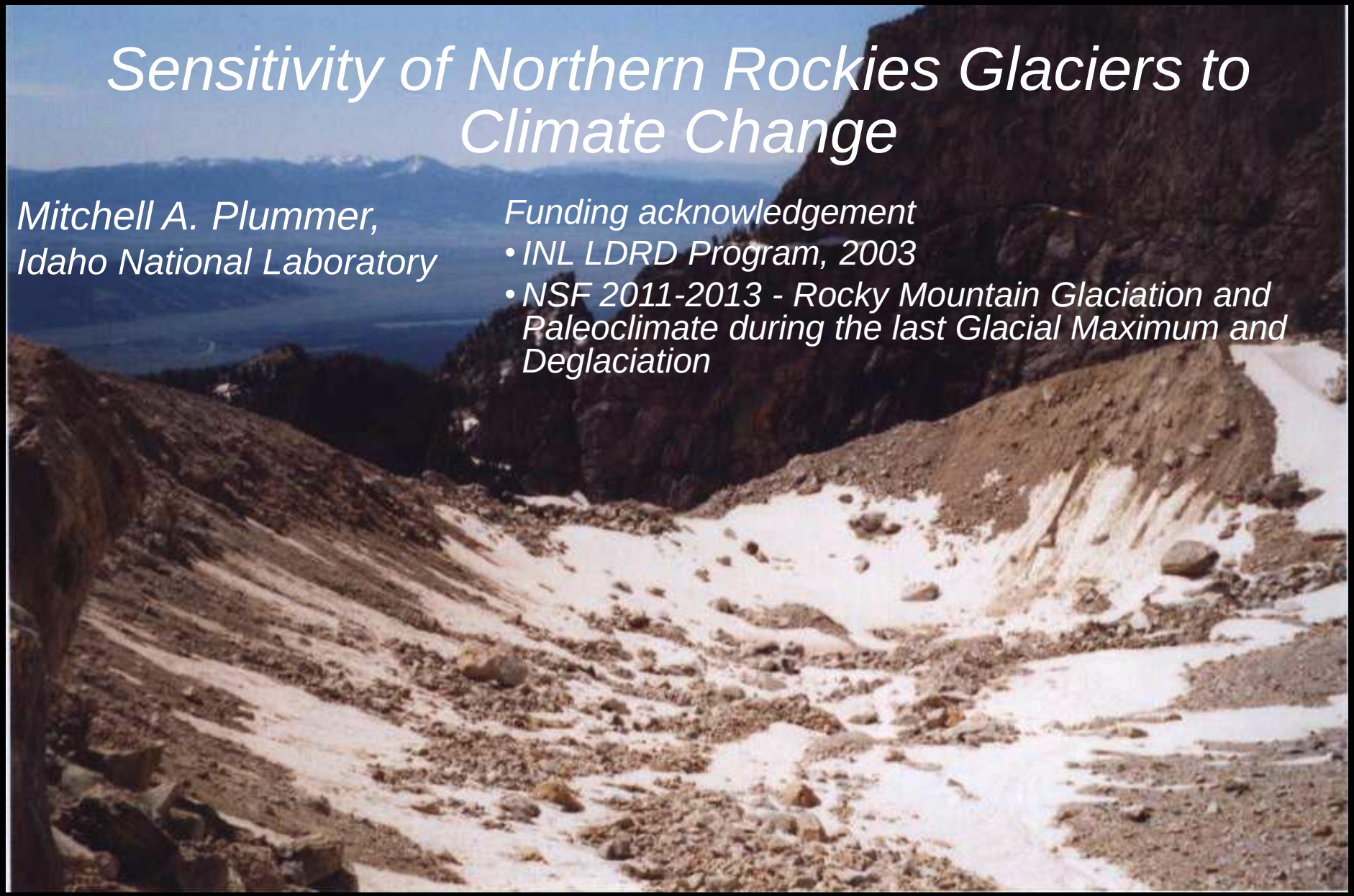


Sensitivity of Northern Rockies Glaciers to Climate Change

Mitchell A. Plummer,
Idaho National Laboratory

Funding acknowledgement

- *INL LDRD Program, 2003*
- *NSF 2011-2013 - Rocky Mountain Glaciation and Paleoclimate during the last Glacial Maximum and Deglaciation*

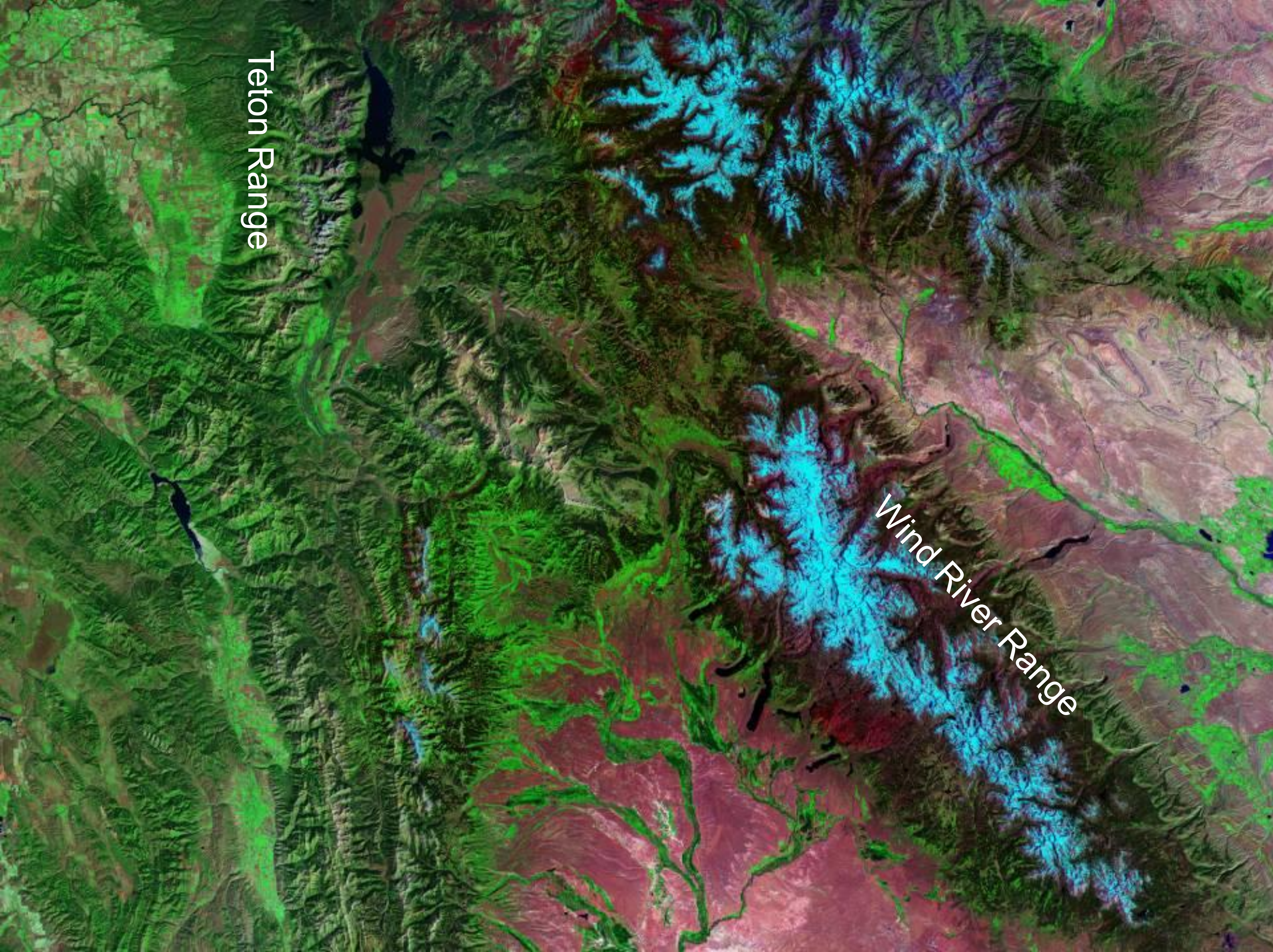
1850

Glacier National Park

- Dry Herbaceous
- Mesic Herbaceous
- Deciduous Tree/Shrub
- Coniferous Open Dry
- Coniferous Dense Mesic
- Grassland
- Glacier
- Rock
- Lakes

USGS
science for a changing world

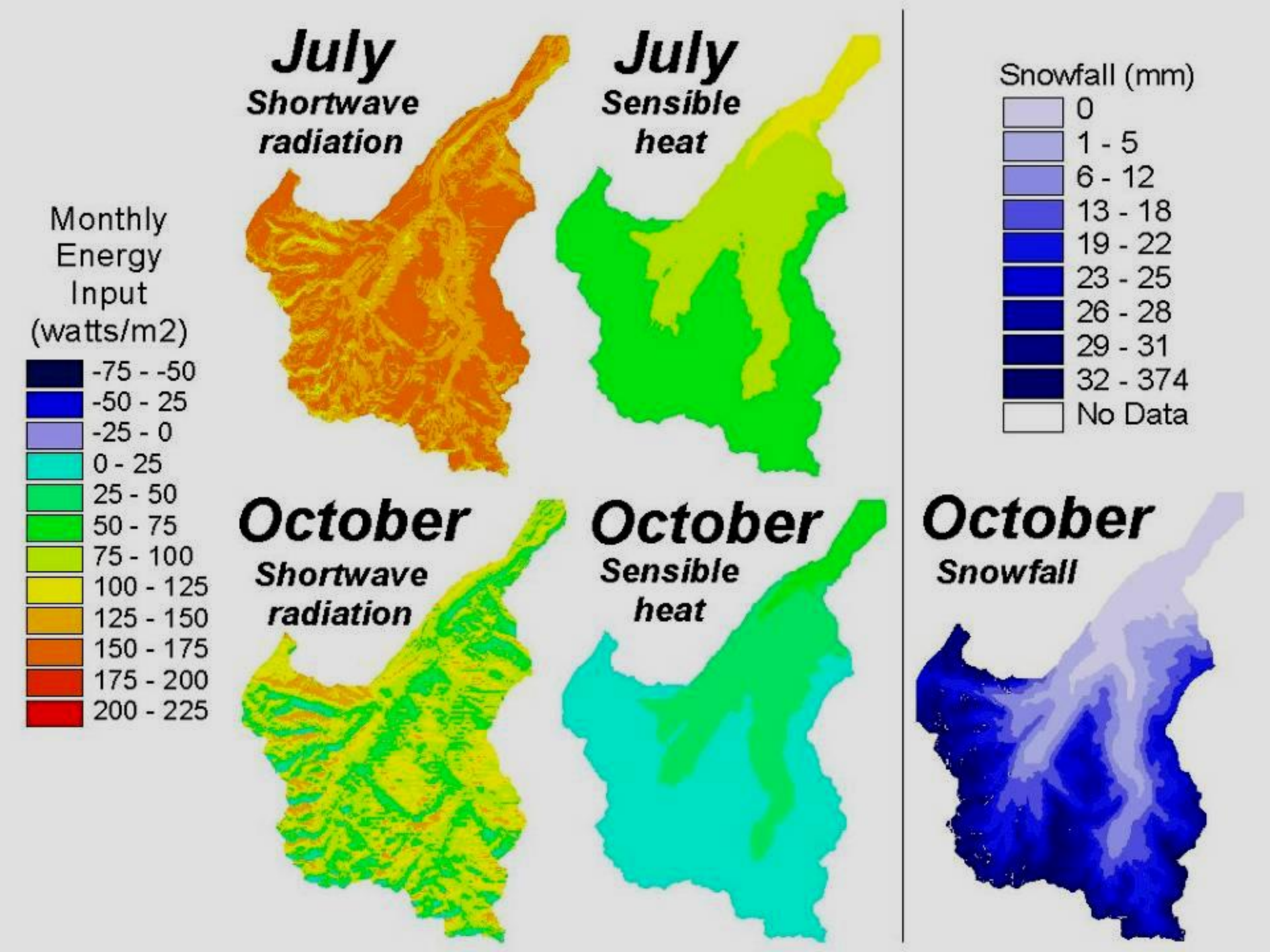
From: Hall and Fagre, 2003
BioScience 53: 131-140

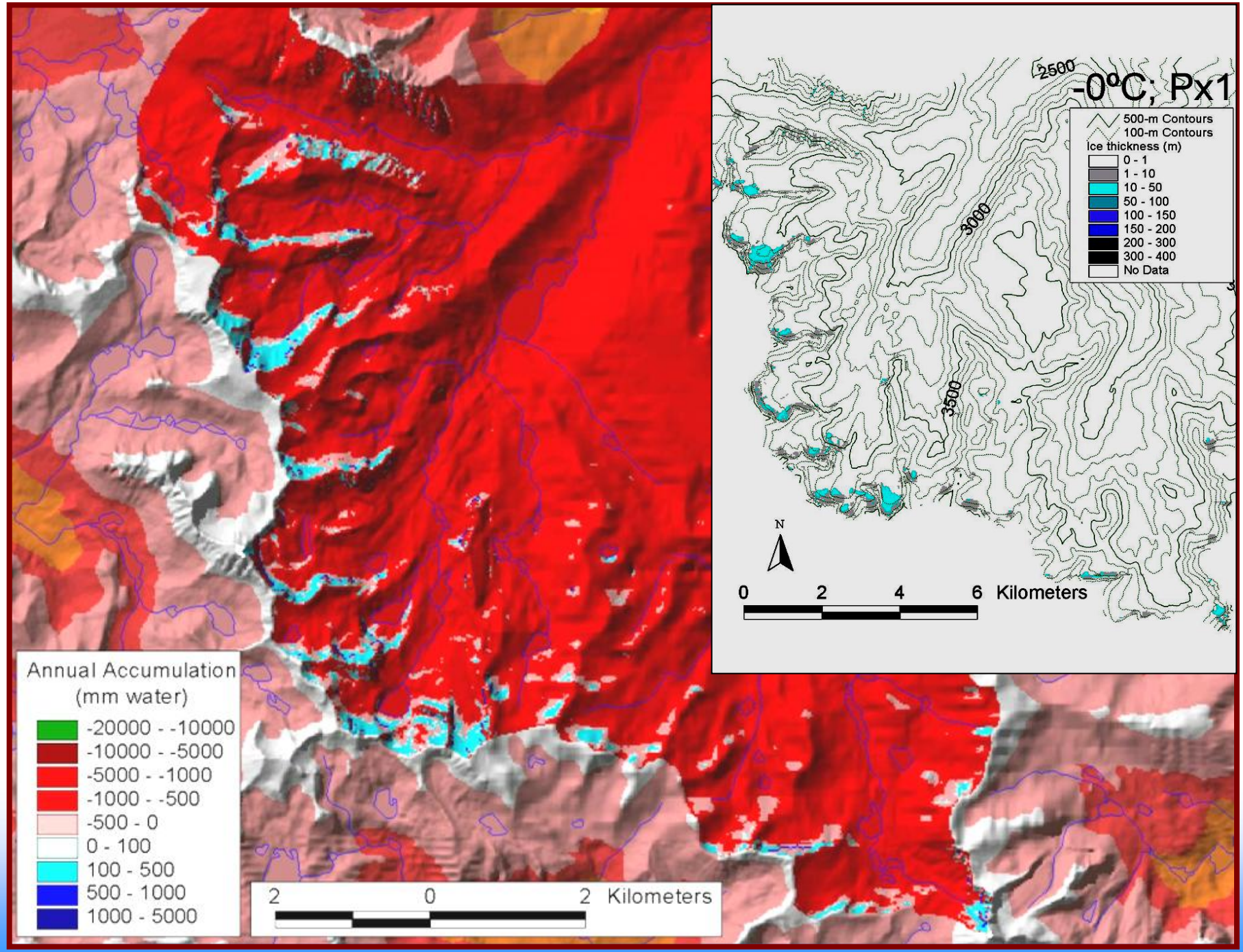

Teton Range
Wind River Range

Net annual ice balance, b_n

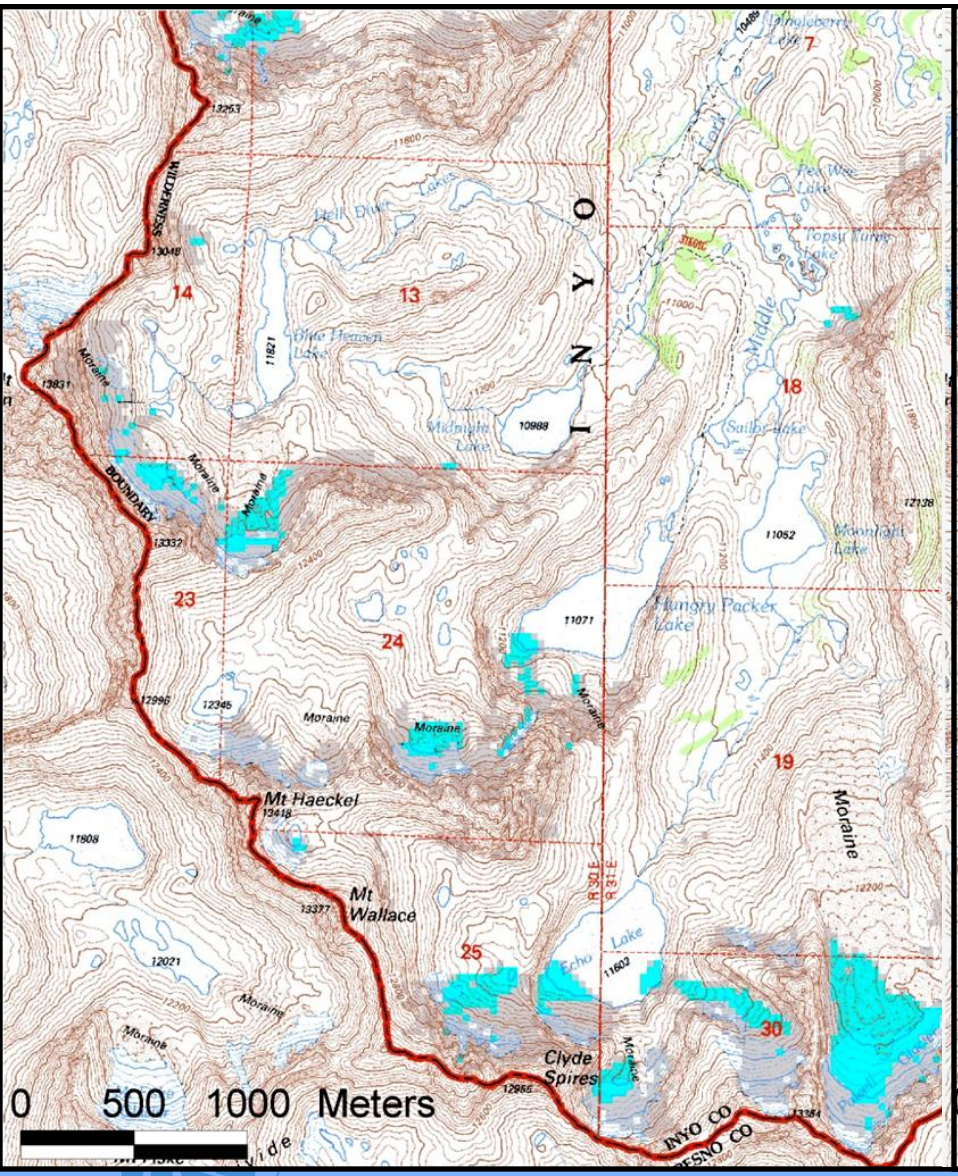
$$b_n = \int_{fall}^{spring} (Snow - E)dt + \int_{spring}^{fall} (Snow - M - E)dt$$

- **b_n = net ice budget at any location in the x,y plane**
- **Snow = total snowfall**
  - **Fraction of precipitation falling as snow**
- **M = mass of snow melted**
  - **Calculated from energy balance when T > 0**
- **E = evaporation & sublimation**
  - **Calculated via turbulent heat transfer equations**

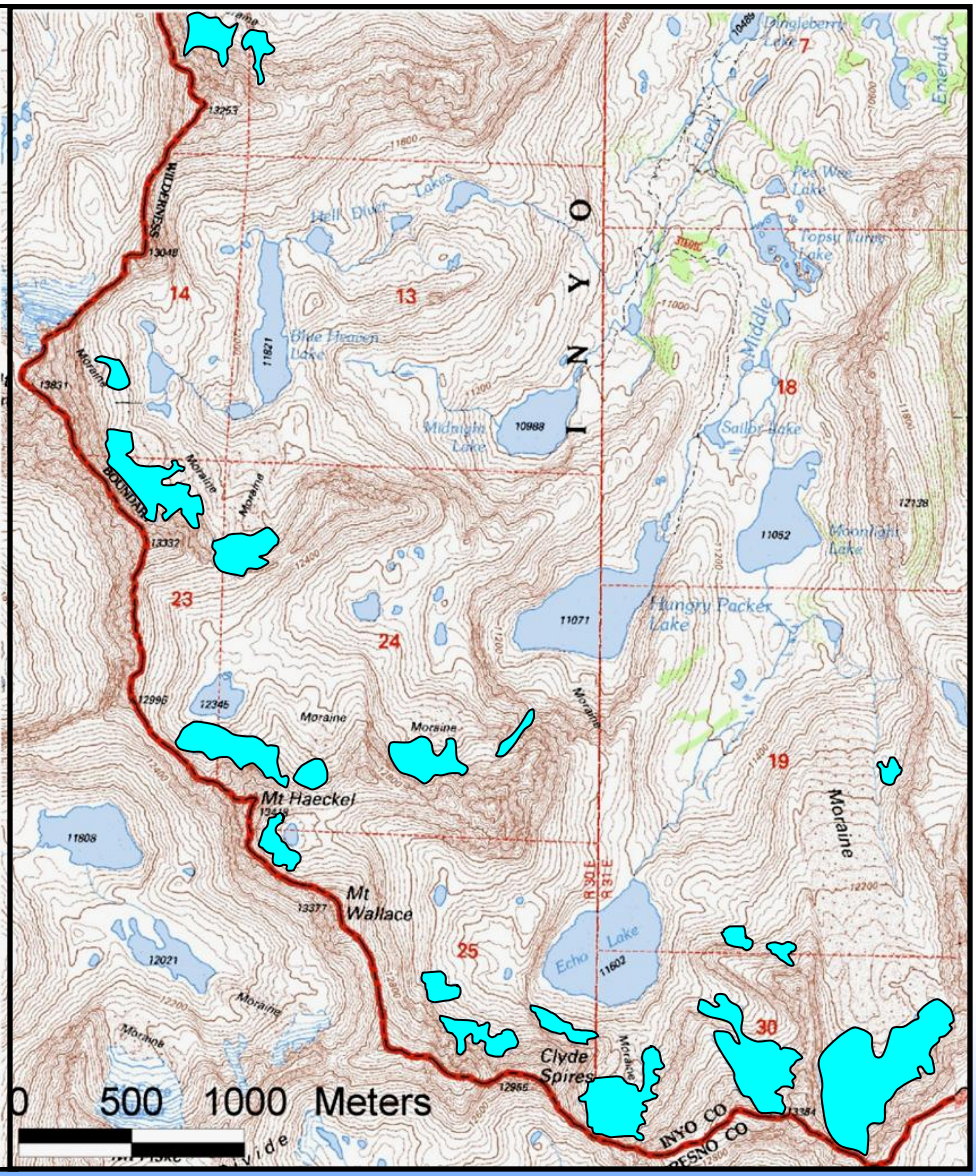

July
Shortwave radiation
July
Sensible heat
Snowfall (mm)
0
1 - 5
6 - 12
13 - 18
19 - 22
23 - 25
26 - 28
29 - 31
32 - 374
No Data
Monthly Energy Input (watts/m2)
-75 - -50
-50 - 25
-25 - 0
0 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
200 - 225
October
Shortwave radiation
October
Sensible heat
October
Snowfall

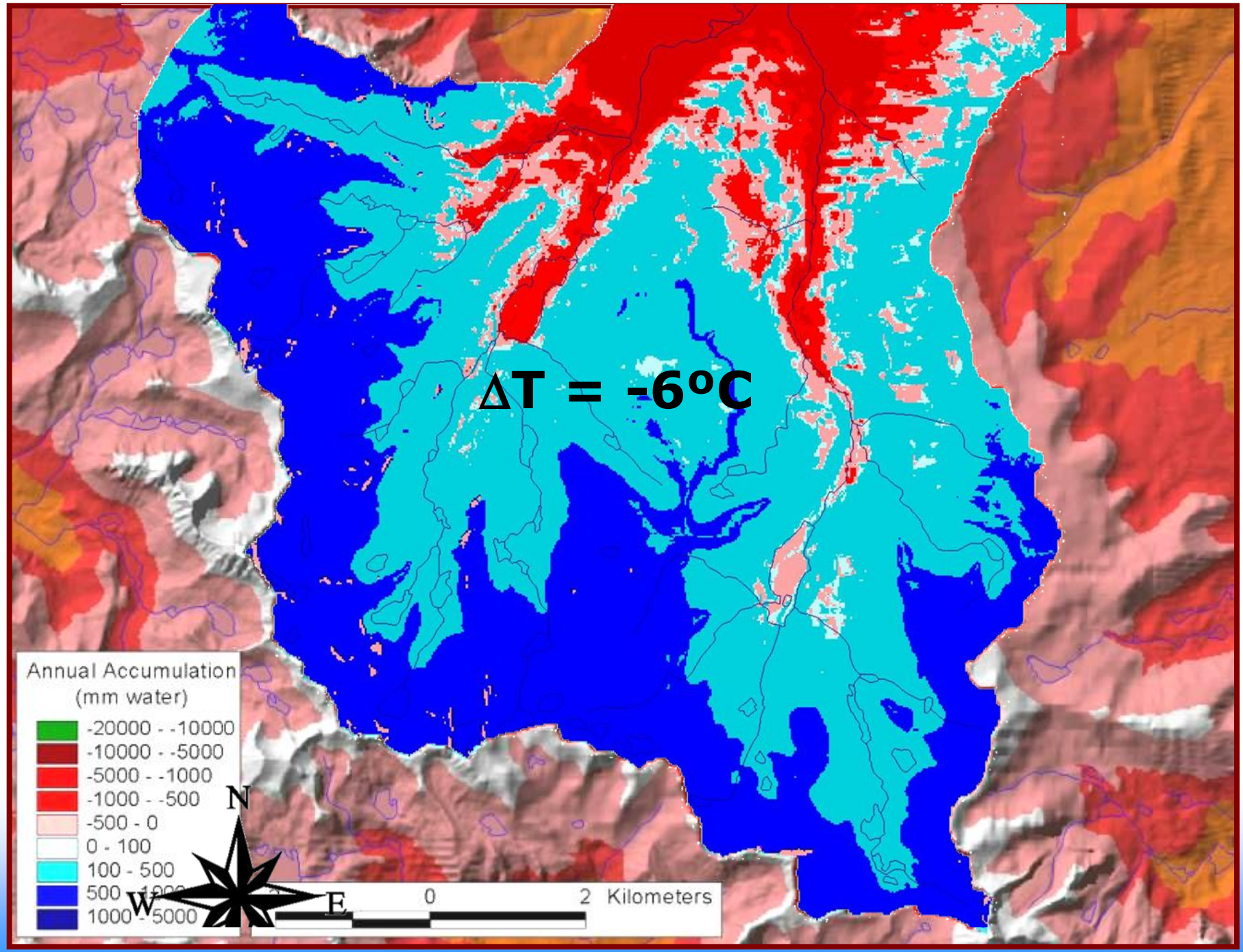

-0°C; Px1
2500
3000
3500
500-m Contours
100-m Contours
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400
No Data
N
0 2 4 6 Kilometers
Annual Accumulation
(mm water)
-20000 - -10000
-10000 - -5000
-5000 - -1000
-1000 - -500
-500 - 0
0 - 100
100 - 500
500 - 1000
1000 - 5000
2 0 2 Kilometers

Modeled Glaciers and Perennial Snow



Mapped Glaciers and Perennial Snow




ΔT = -6ºC
Annual Accumulation
(mm water)
-20000 - -10000
-10000 - -5000
-5000 - -1000
-1000 - -500
-500 - 0
0 - 100
100 - 500
500 - 1000
1000 - 5000
N
W
E
0
2 Kilometers


Ice thickness (m)
400
300
200
100
50
Coords years
elapsed

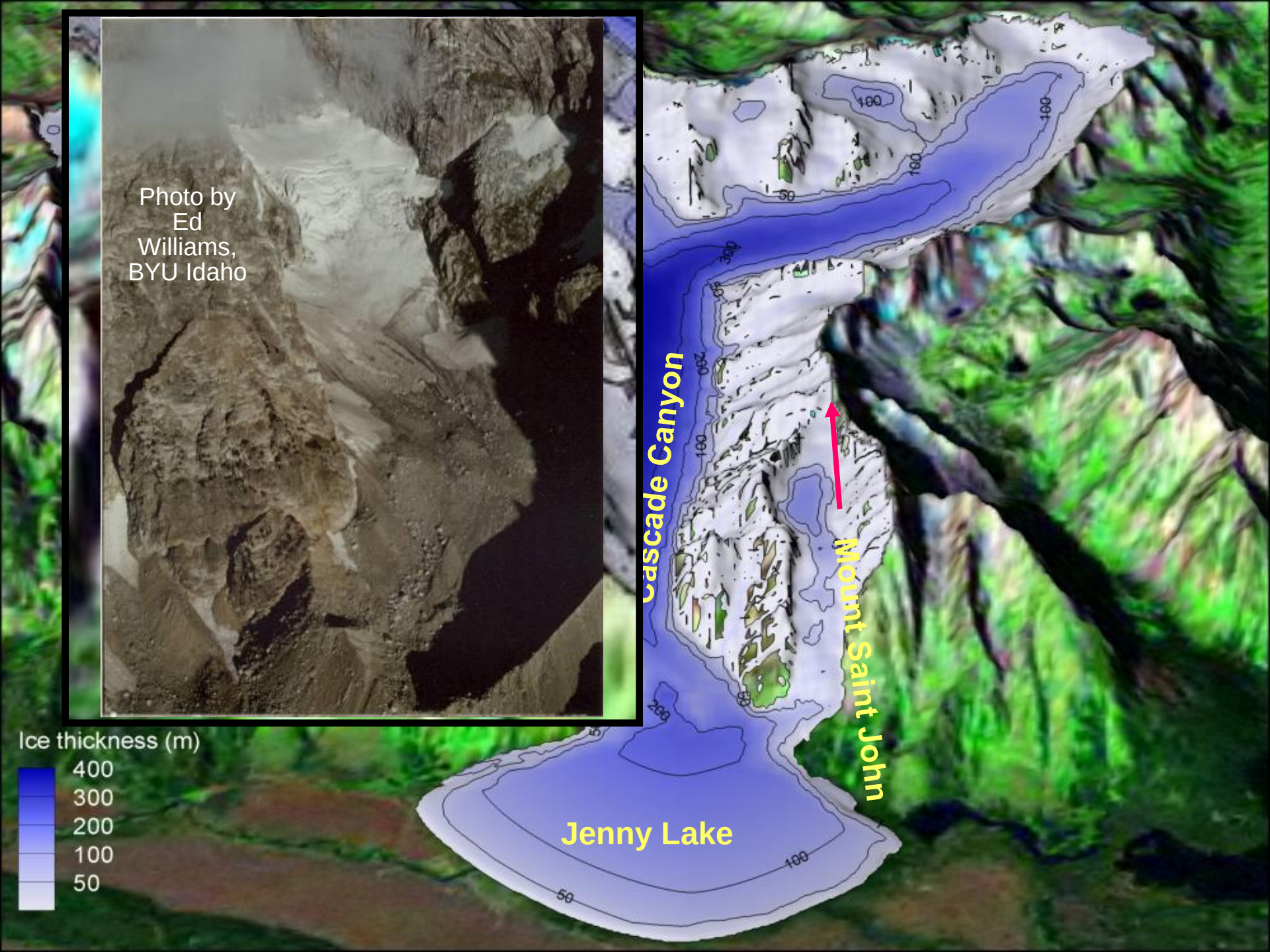
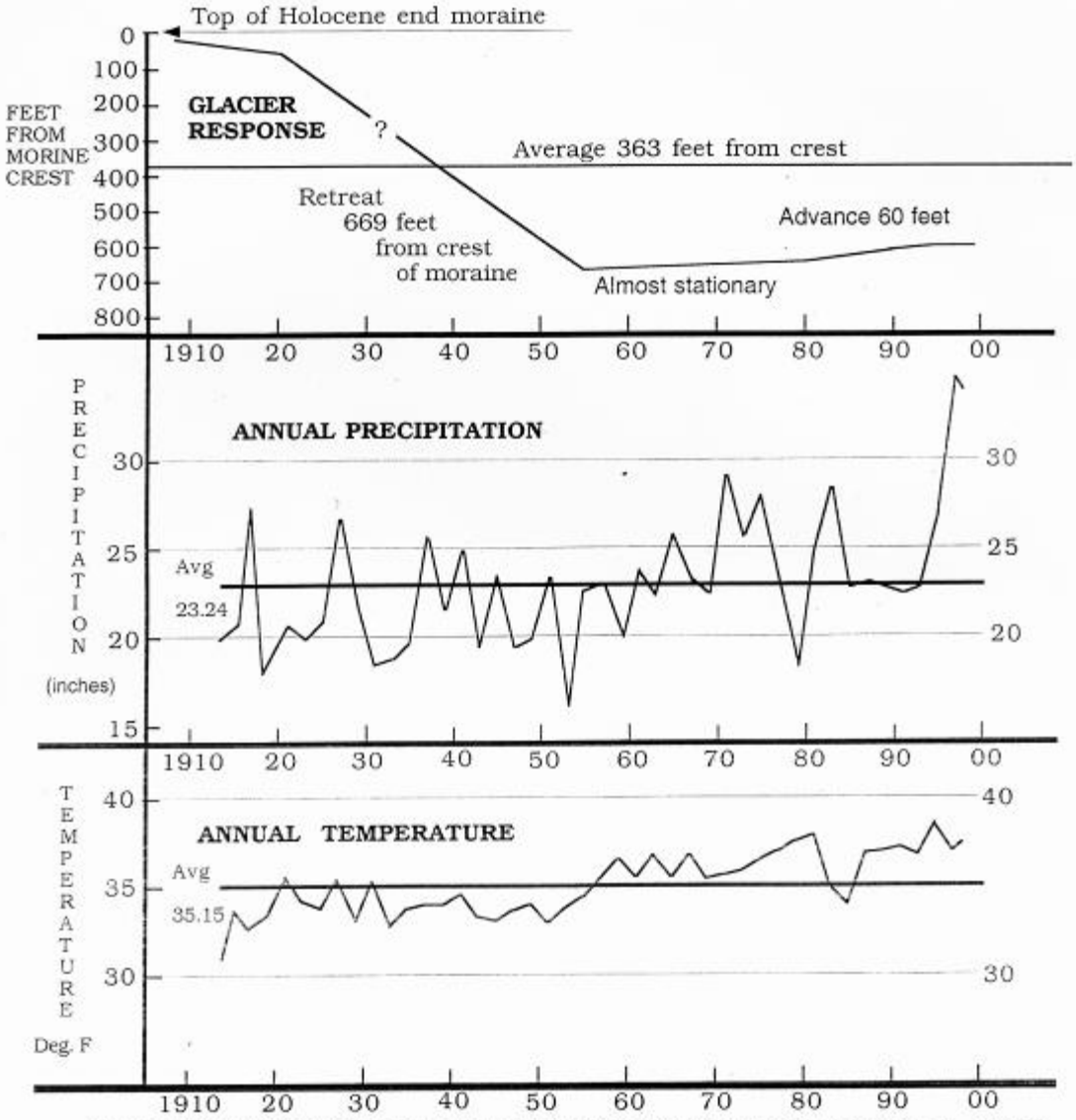


Photo by Ed Williams, BYU Idaho
Cascade Canyon
Mount Saint John
Jenny Lake
Ice thickness (m)
400
300
200
100
50

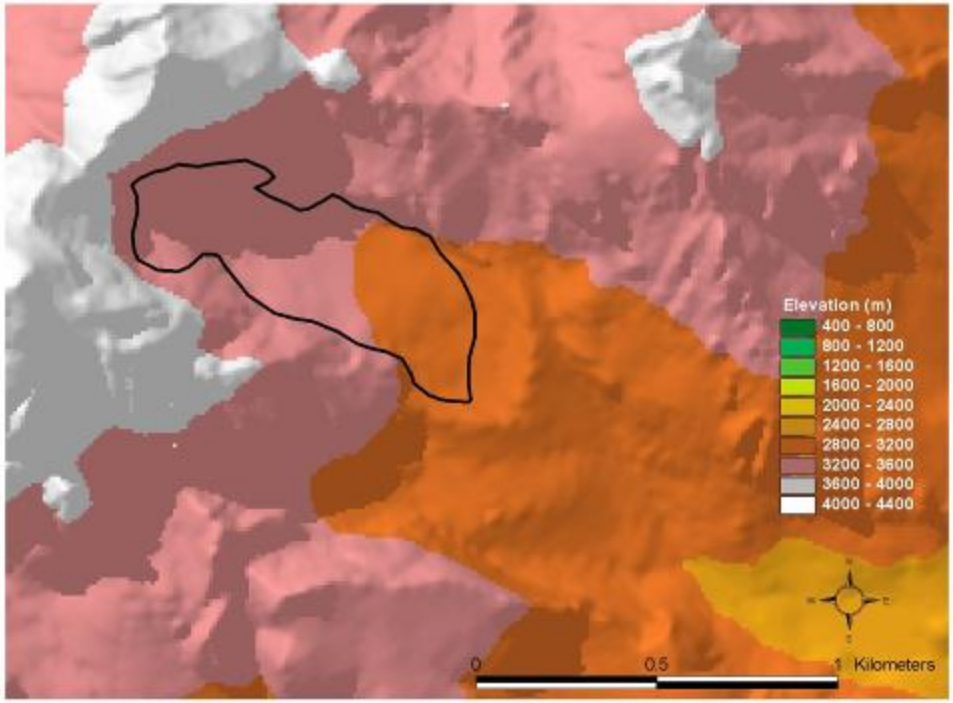
TETON GLACIER RESPONSE TO CLIMATE CHANGES

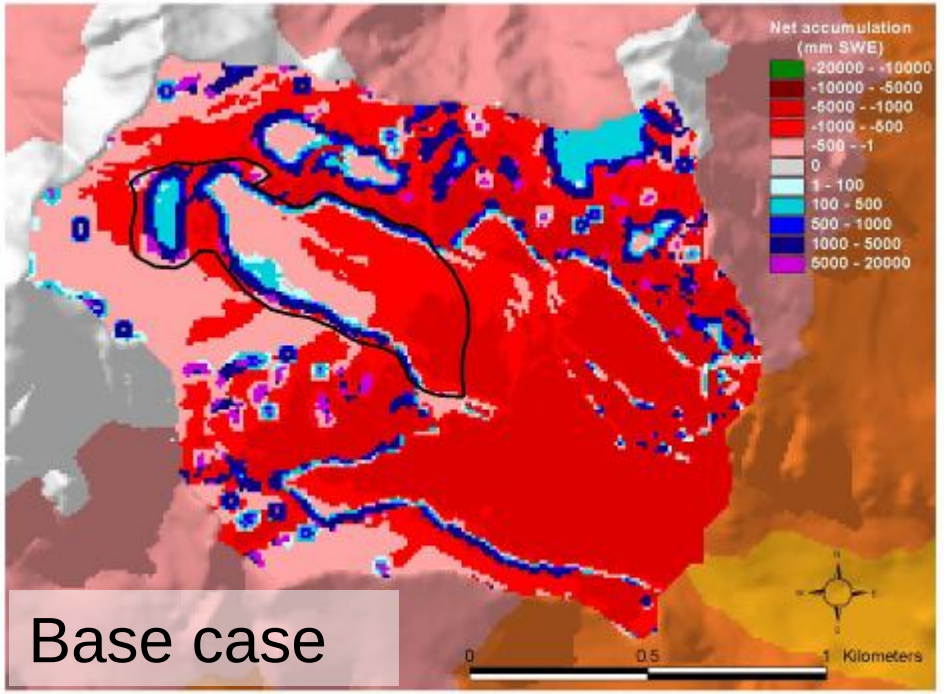


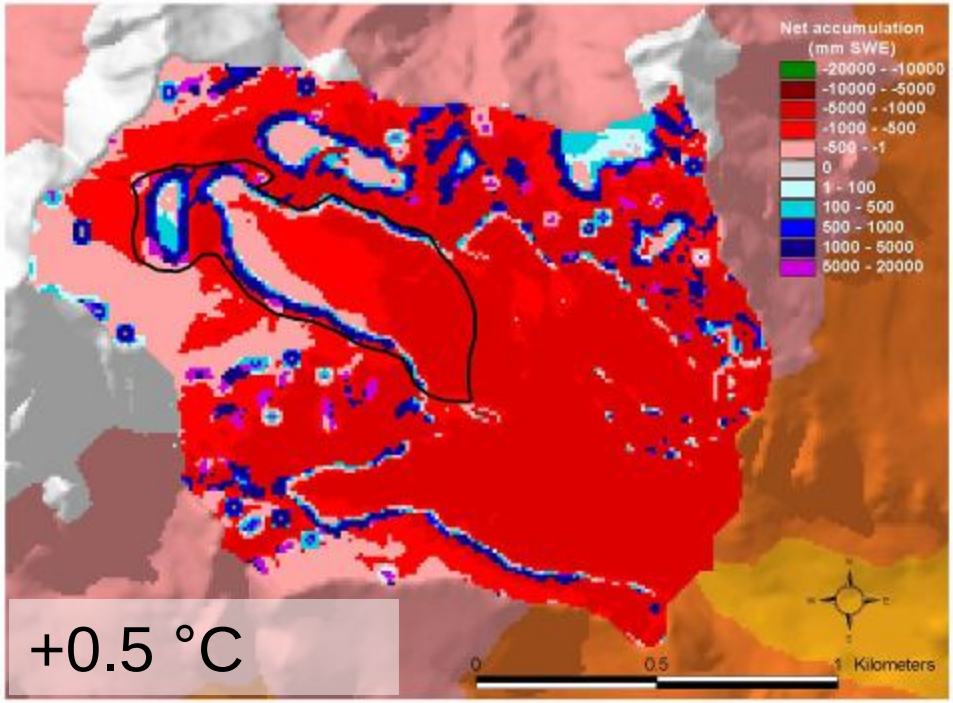
RESPONSE OF TETON GLACIER TO CLIMATE CHANGES 1914 - 1998.
Weather records are from the Moran Weather Station in Teton National Park.

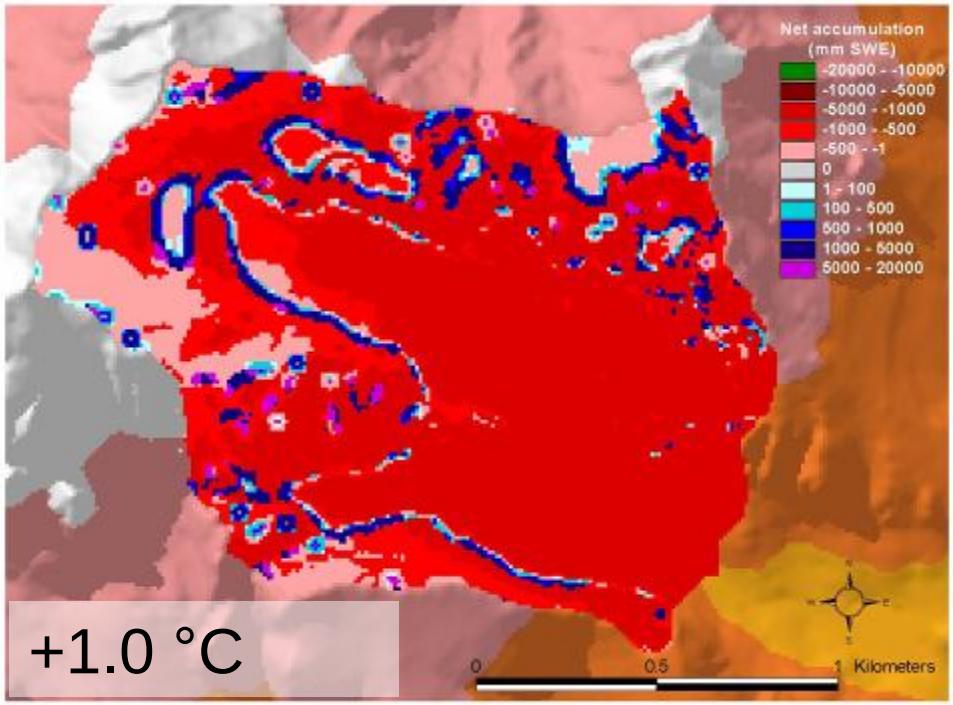
Average Precipitation 1914-1955 = 21.3 in. Average precipitation 1956 - 1998 = 24.5 in.
Average Temperature 1914-1955 = 34 deg F. Average Temperature 1956-1998 = 37.8 deg

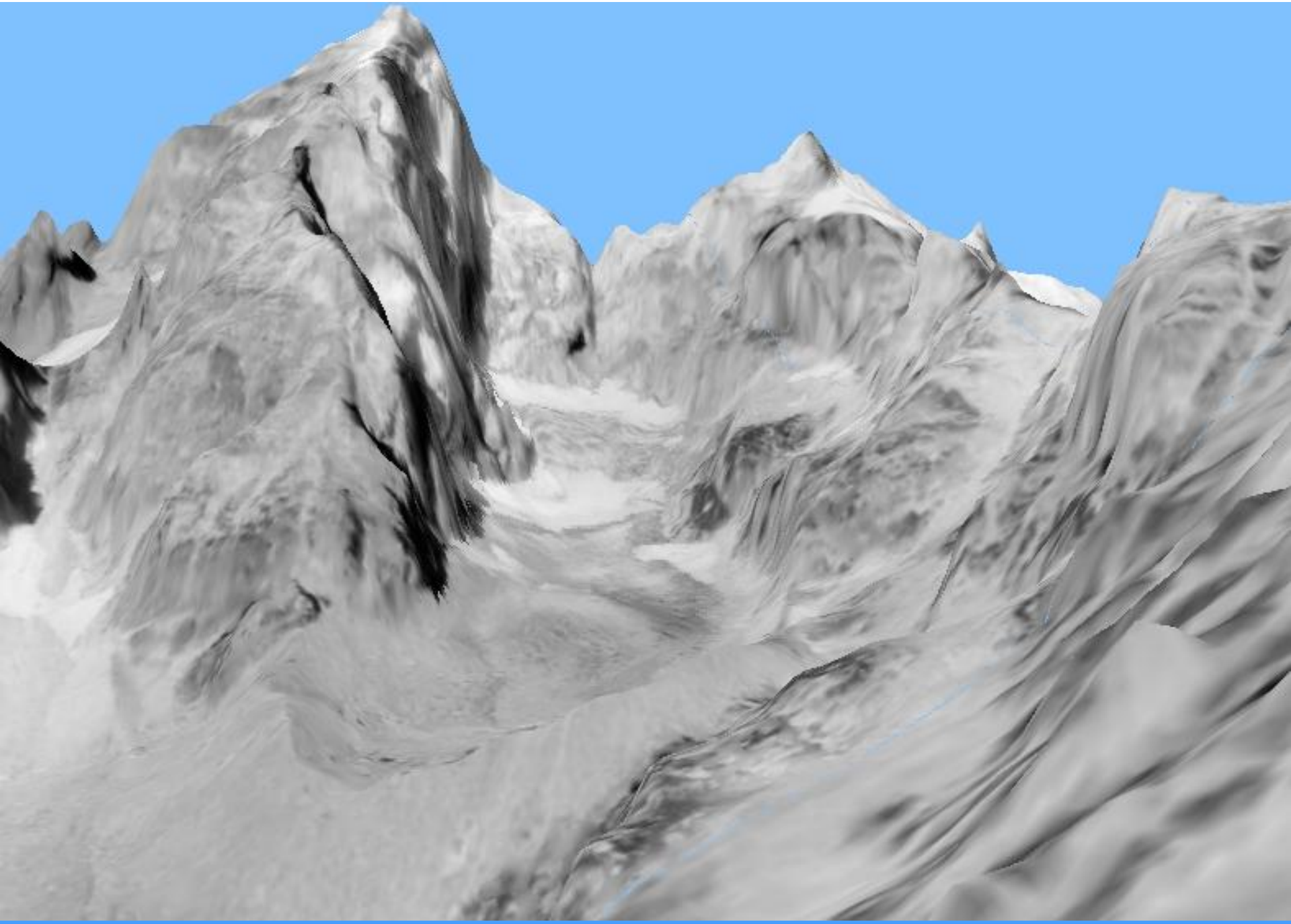
Figure 96: The Teton glacier, showing its retreat since its maximum advance during the Little Ice Age, represented by the sharp-crested fresh moraine. Approximate positions of the ice terminus at different times shown by red lines. Photo by E.J. Williams, 1998.

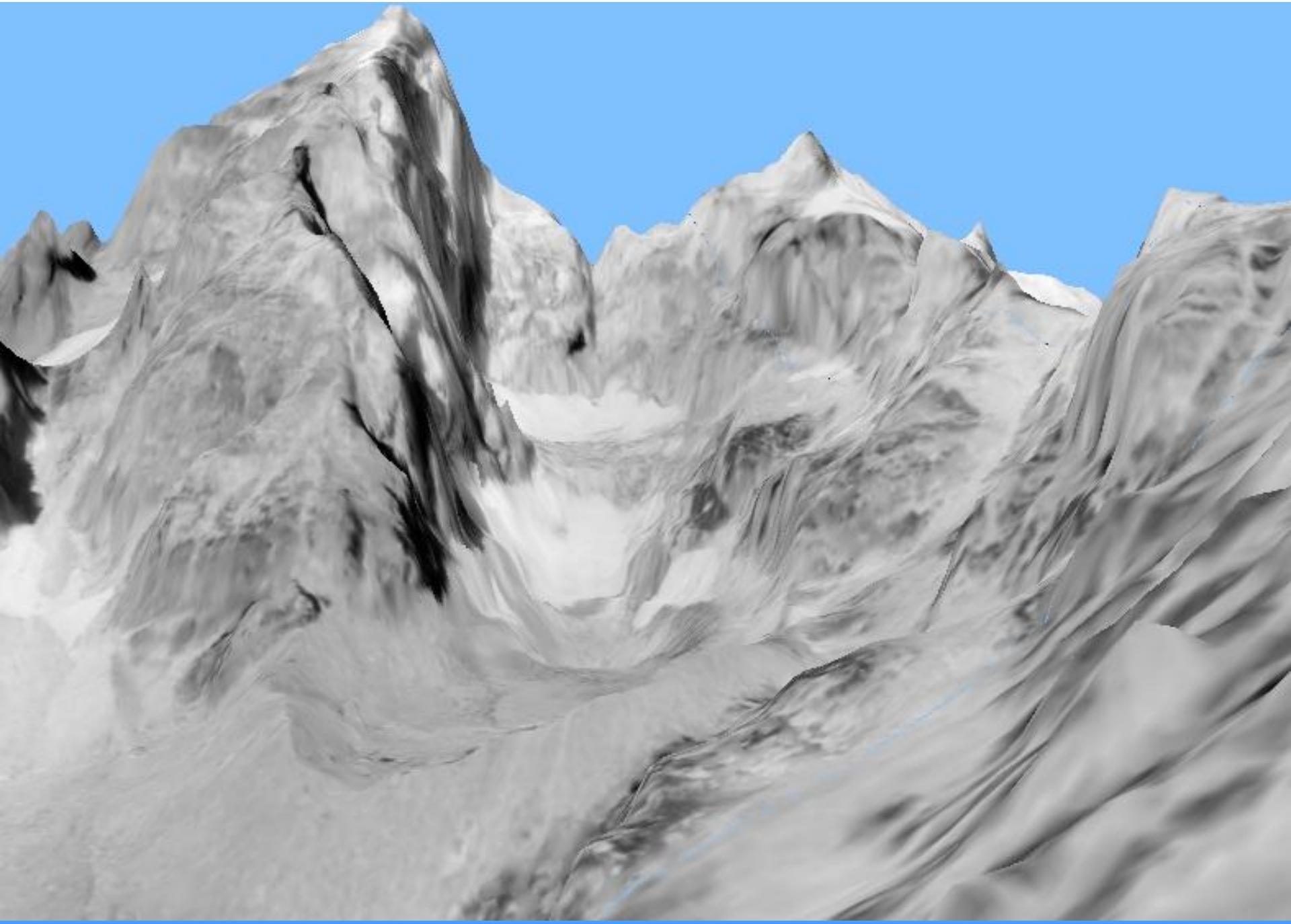

Elevation (m)
400 - 800
800 - 1200
1200 - 1600
1600 - 2000
2000 - 2400
2400 - 2800
2800 - 3200
3200 - 3600
3600 - 4000
4000 - 4400
0
0.5
1 Kilometers

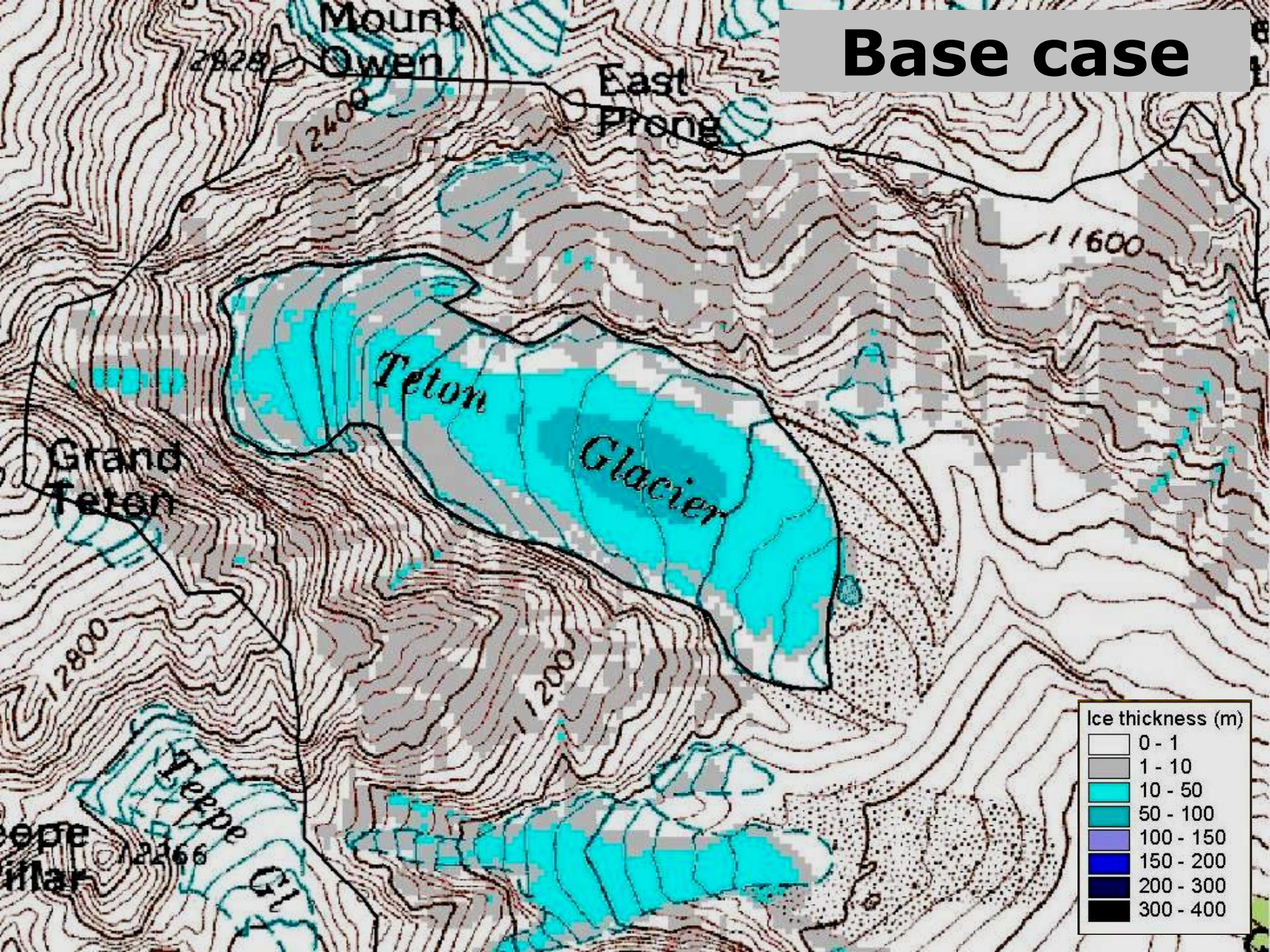

Net accumulation
(mm SWE)
-20000 - -10000
-10000 - -5000
-5000 - -1000
-1000 - -500
-500 - -1
0
1 - 100
100 - 500
500 - 1000
1000 - 5000
5000 - 20000
Base case
0
0.5
1 Kilometers

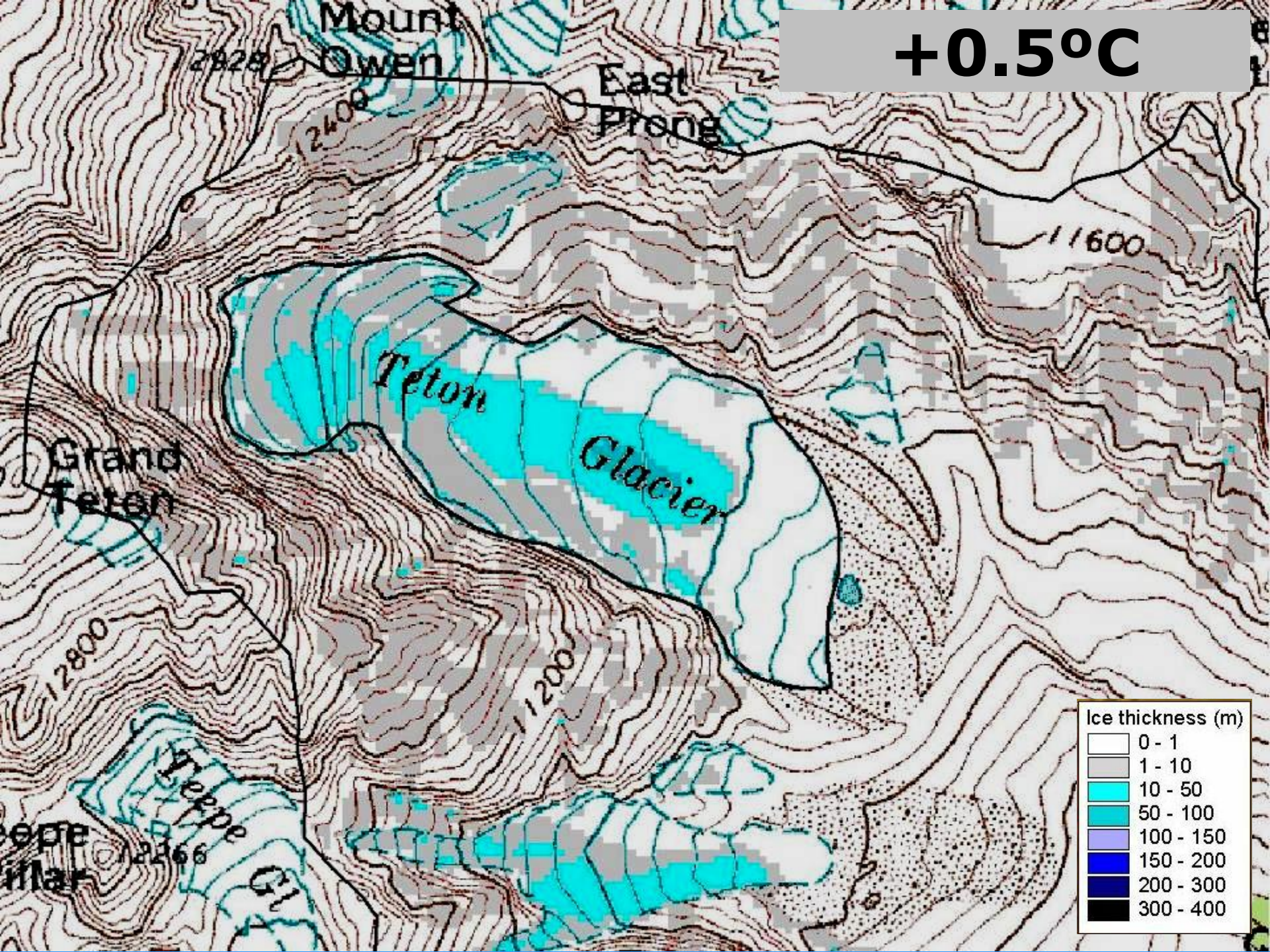

Net accumulation
(mm SWE)
-20000 - -10000
-10000 - -5000
-5000 - -1000
-1000 - -500
-500 - -1
0
1 - 100
100 - 500
500 - 1000
1000 - 5000
5000 - 20000
+0.5 °C
0
0.5
1 Kilometers

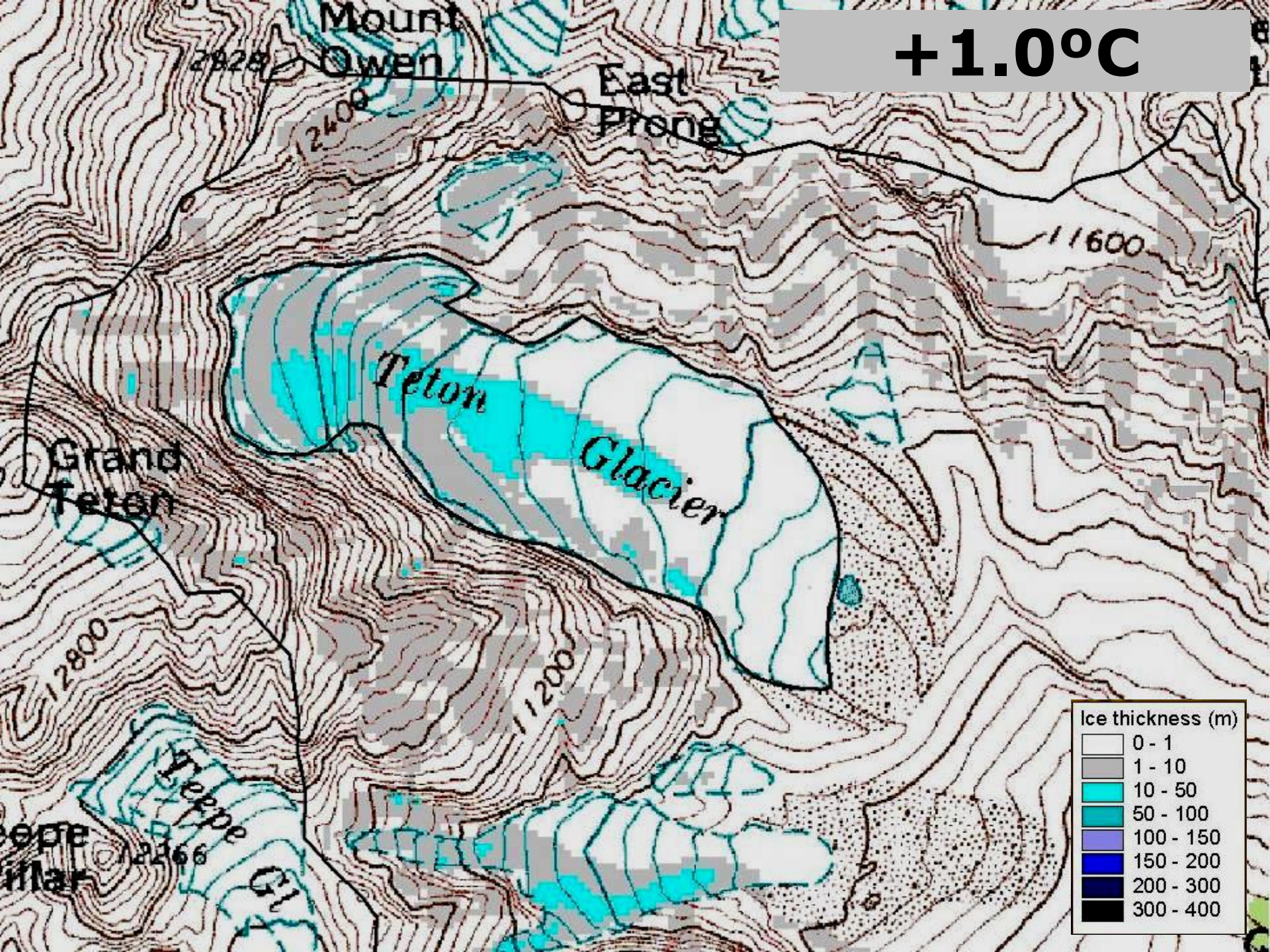

Net accumulation
(mm SWE)
-20000 - -10000
-10000 - -5000
-5000 - -1000
-1000 - -500
-500 - -1
0
1 - 100
100 - 500
500 - 1000
1000 - 5000
5000 - 20000
+1.0 °C
0
0.5
1 Kilometers

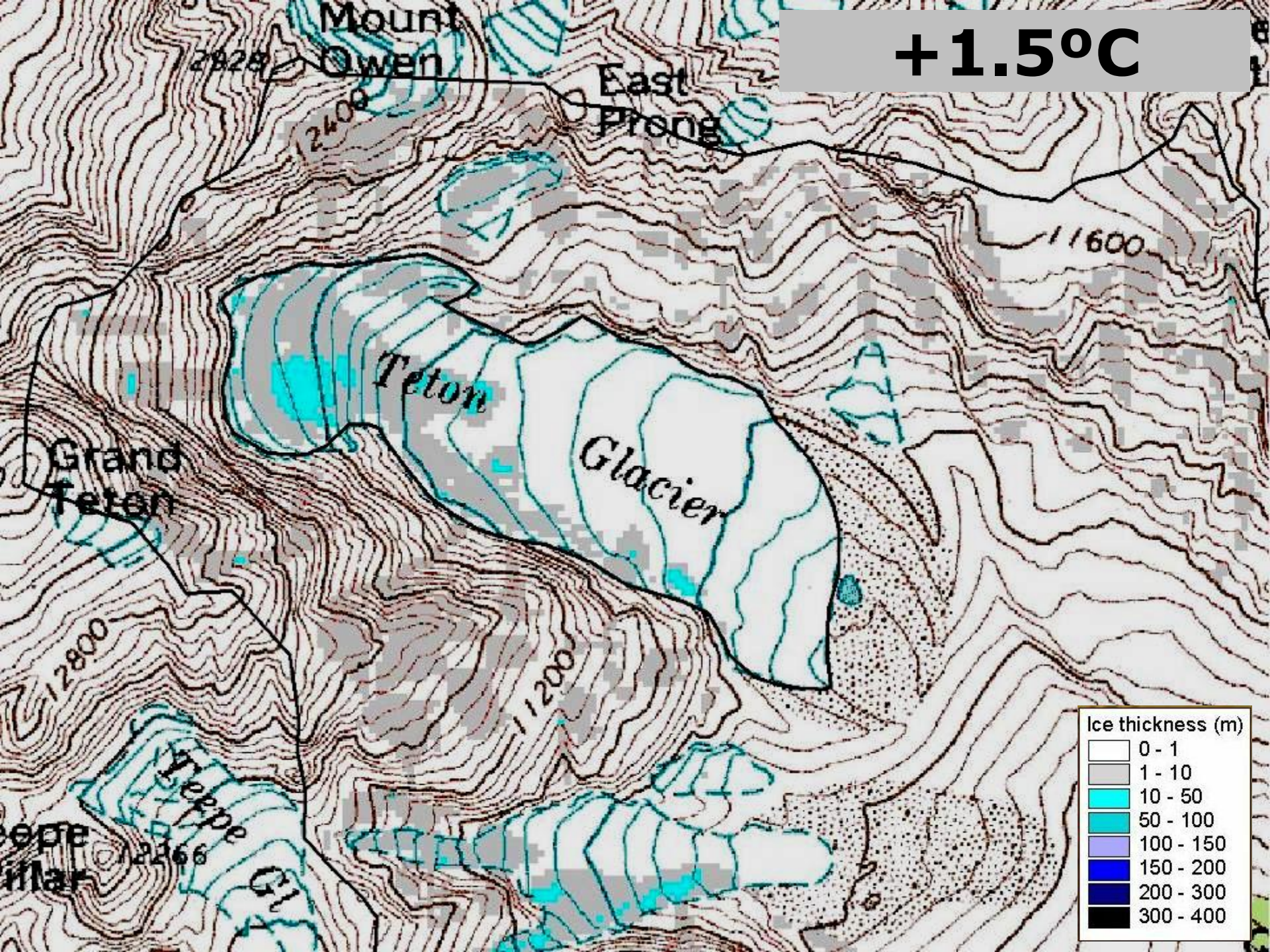


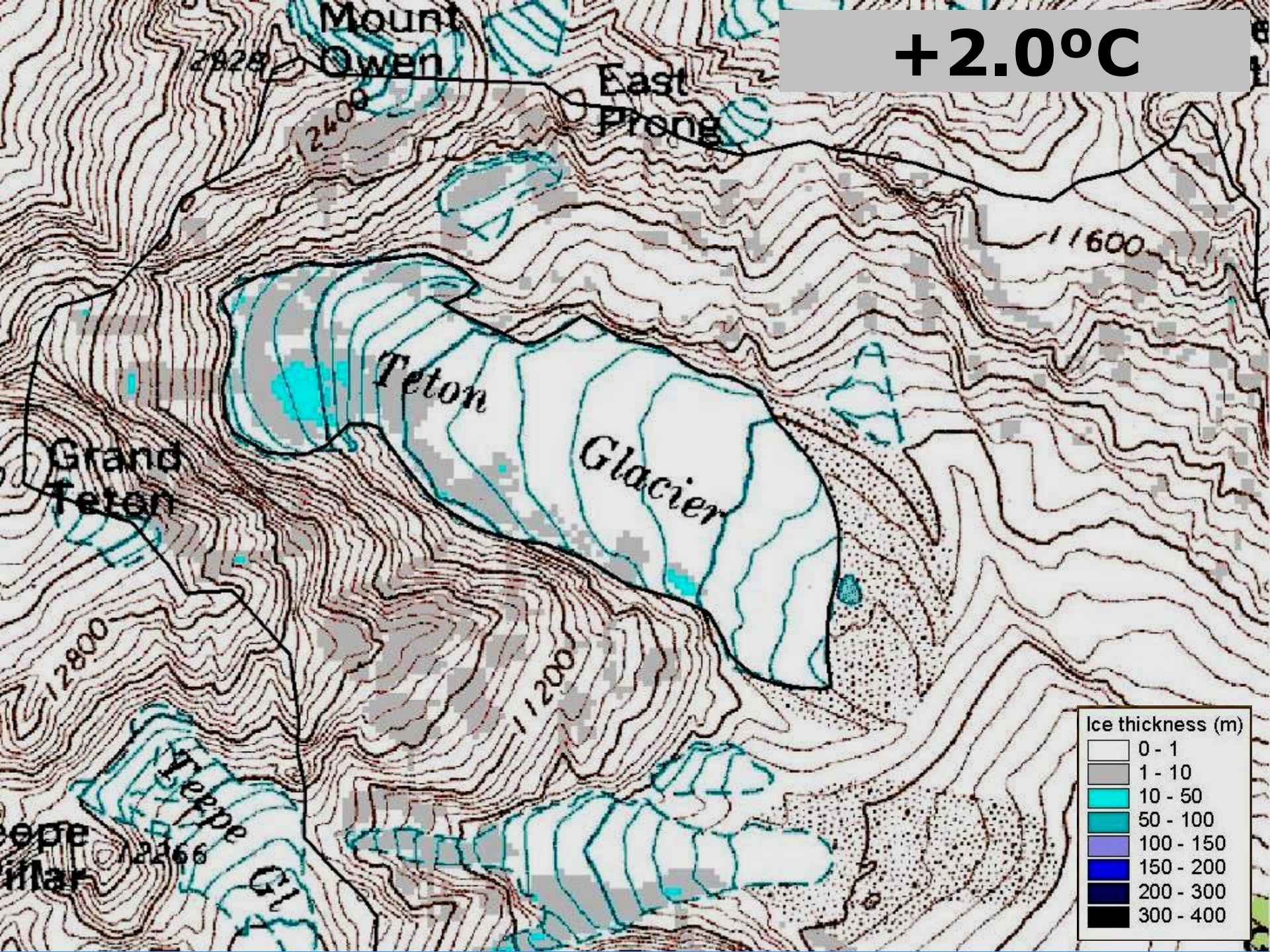


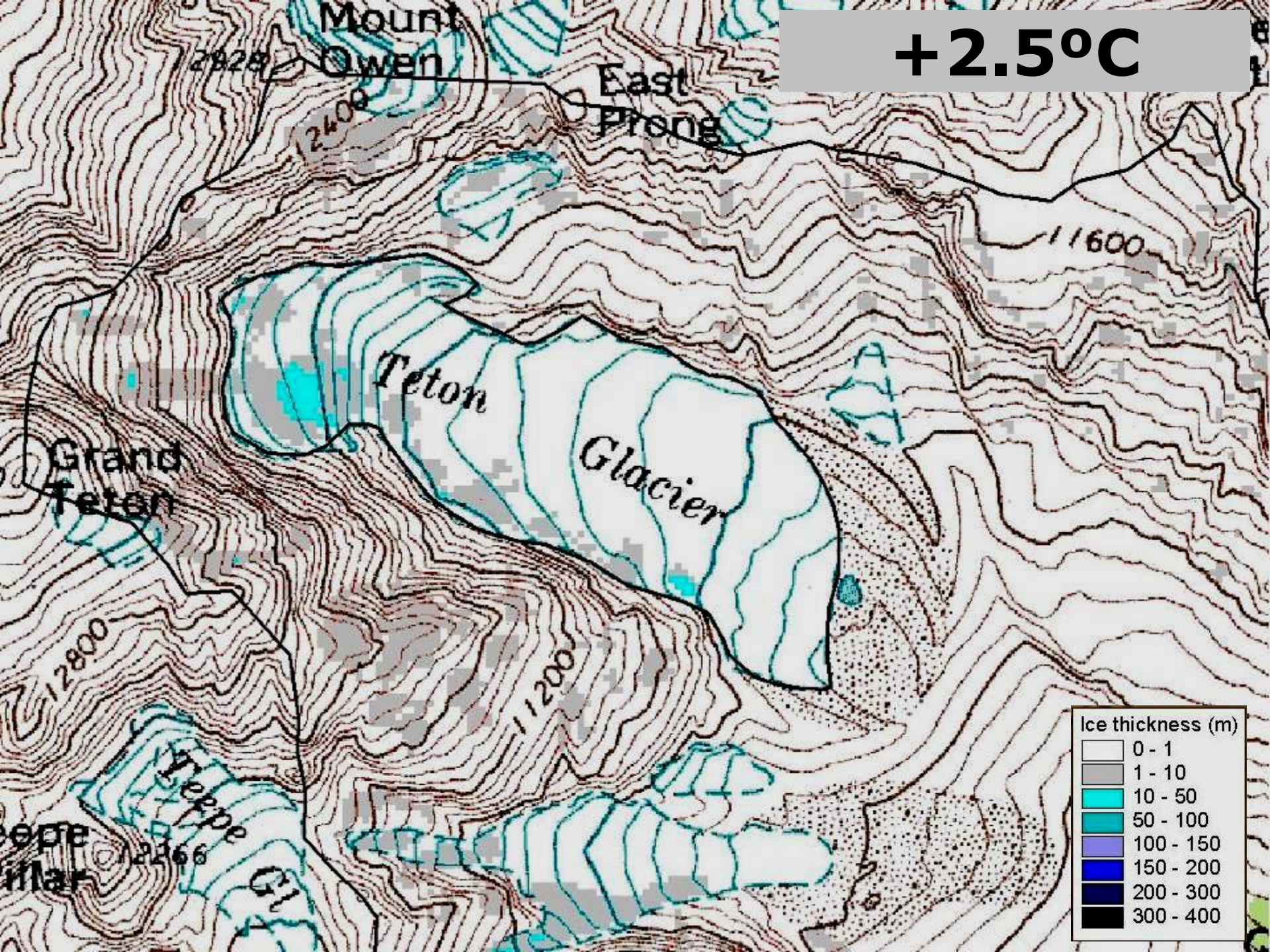

Base case
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12800
11200
12366
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400


+0.5ºC
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12800
11200
12366
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400


+1.0ºC
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12800
11200
12366
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400


+1.5ºC
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12800
11200
12366
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400


+2.0ºC
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12400
12800
11200
12366
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400


+2.5ºC
Mount Owen
East Prong
Teton Glacier
Grand Teton
11600
12800
11200
12160
Ice thickness (m)
0 - 1
1 - 10
10 - 50
50 - 100
100 - 150
150 - 200
200 - 300
300 - 400

From Reynolds (2011), Recent Fluctuations in Grand Teton National Park, Wyoming, Masters Thesis, ISU.

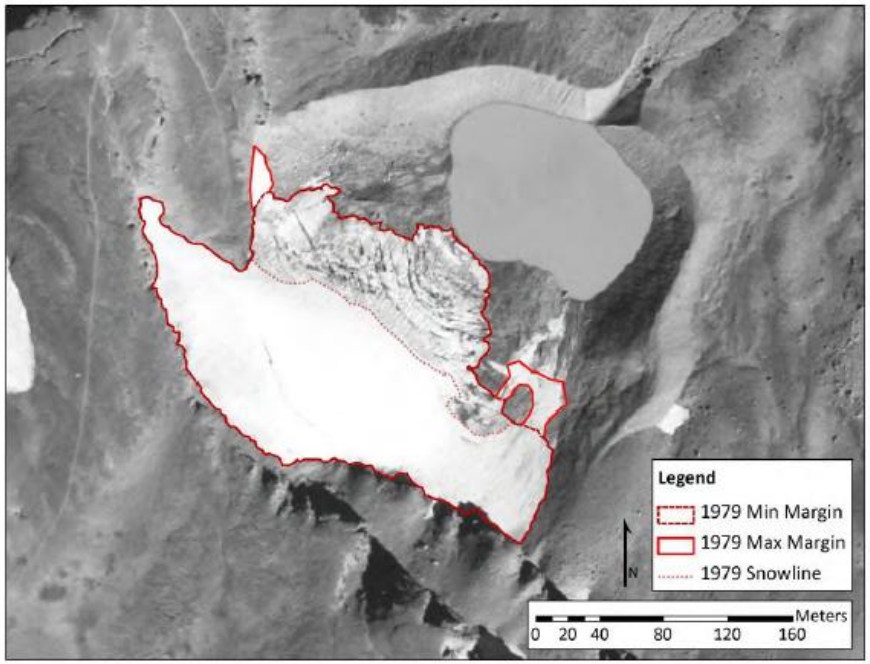


Figure 9. Schoolroom Glacier in 1979.

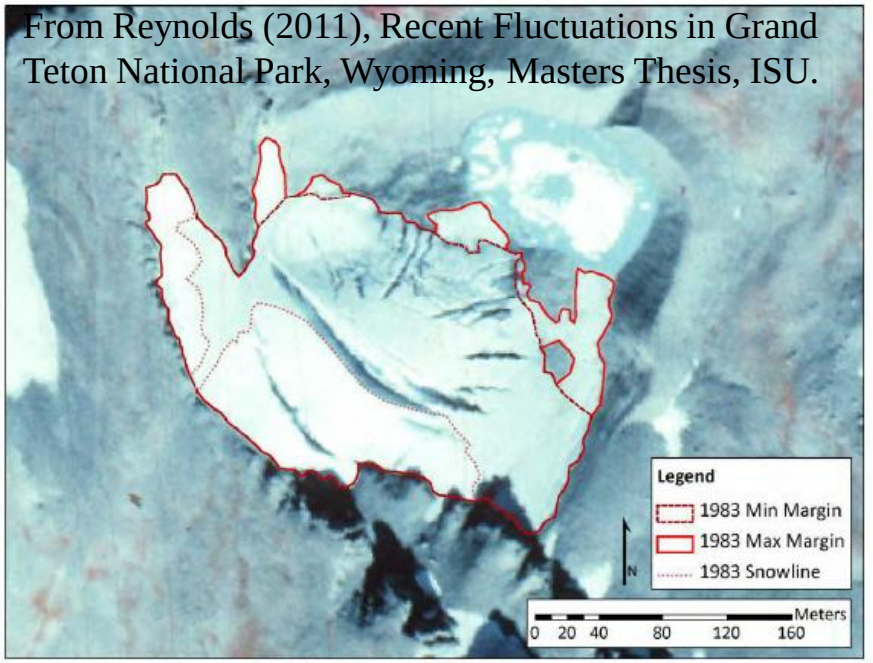


Figure 10. Schoolroom Glacier in 1983.

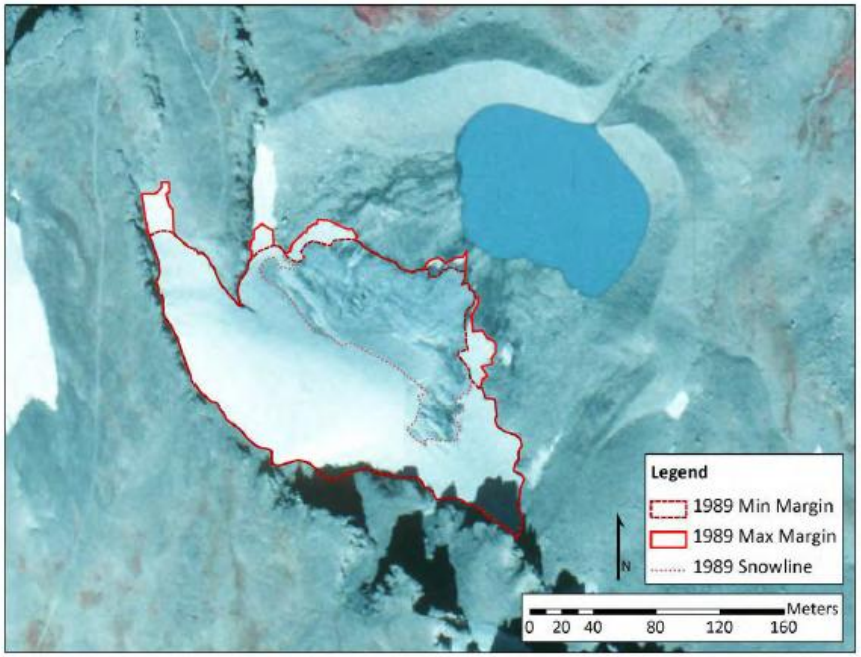


Figure 11. Schoolroom Glacier in 1989.

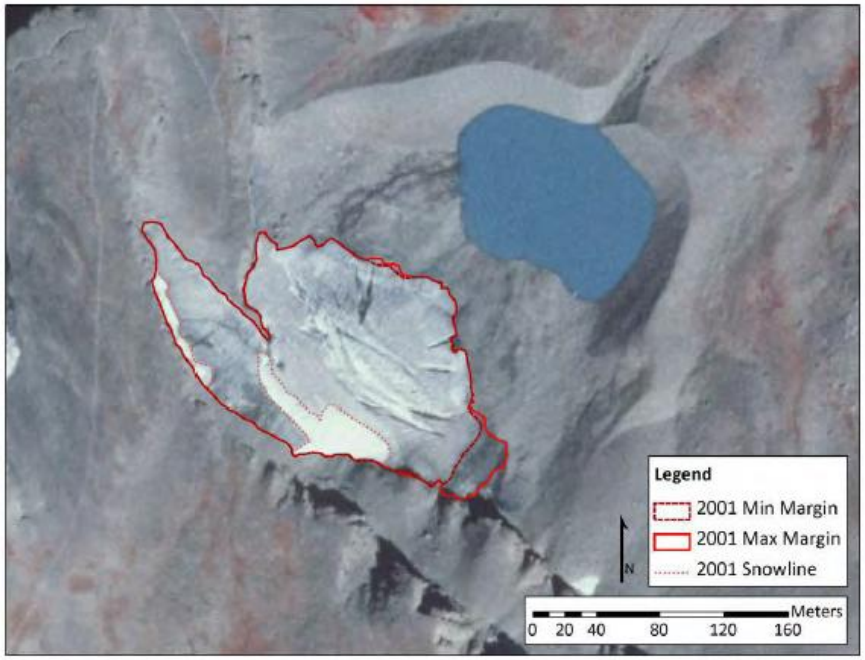
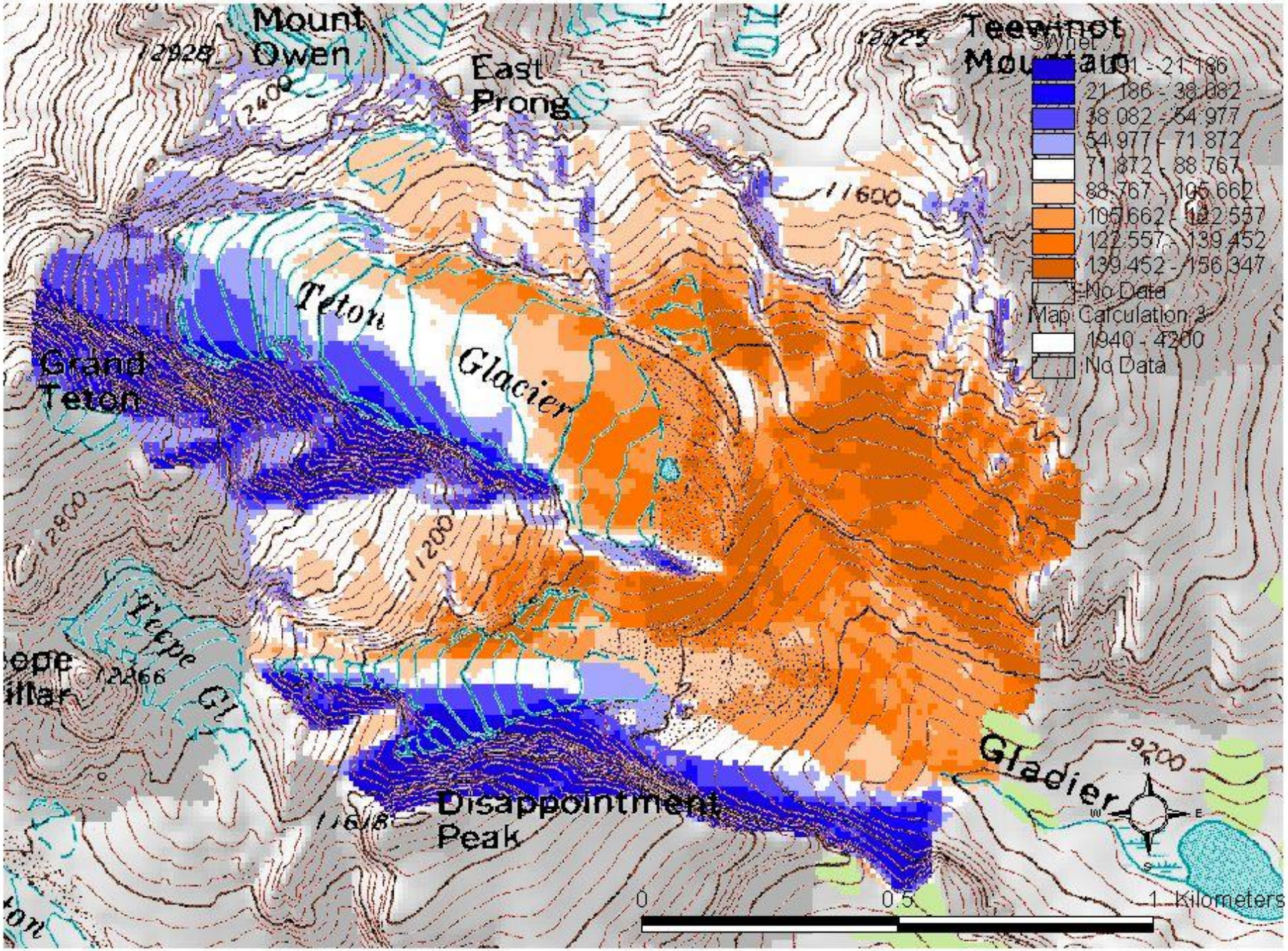


Figure 13. Schoolroom Glacier in 2001.

Remote glaciers tend to receive less attention than more easily accessible glaciers, even though they may be more strongly affected by climate warming (Arendt et al., 2002). Area fluctuation of glaciers in GTNP can be indicators not only of regional climate change, but also of the broader impacts of climate change on the region.

From Reynolds (2011), Recent Fluctuations in Grand Teton National Park, Wyoming, Masters Thesis, ISU.


Mount Owen
East Prong
Teewinot Mountain
Teton Glacier
Grand Teton
Disappointment Peak
Gladier
12928
12925
12866
11600
11200
9200
Sunset
21,186 - 38,082
38,082 - 54,977
54,977 - 71,872
71,872 - 88,767
88,767 - 105,662
105,662 - 122,557
122,557 - 139,452
139,452 - 156,347
No Data
Map Calculation 3
1940 - 4200
No Data
0
0.5
1 Kilometers

Skillet and Falling Ice Glaciers:

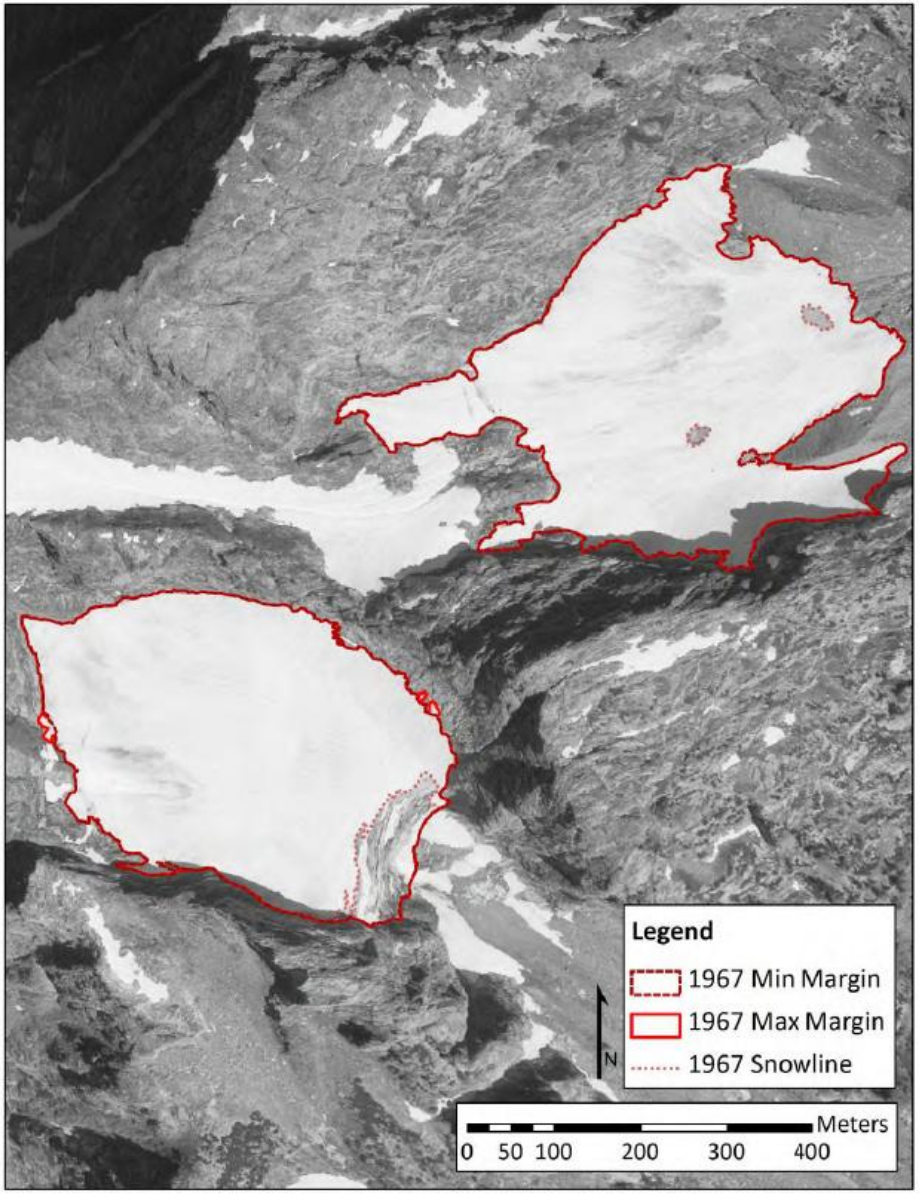


Figure 16. Skillet and Falling Ice Glaciers in 1967.

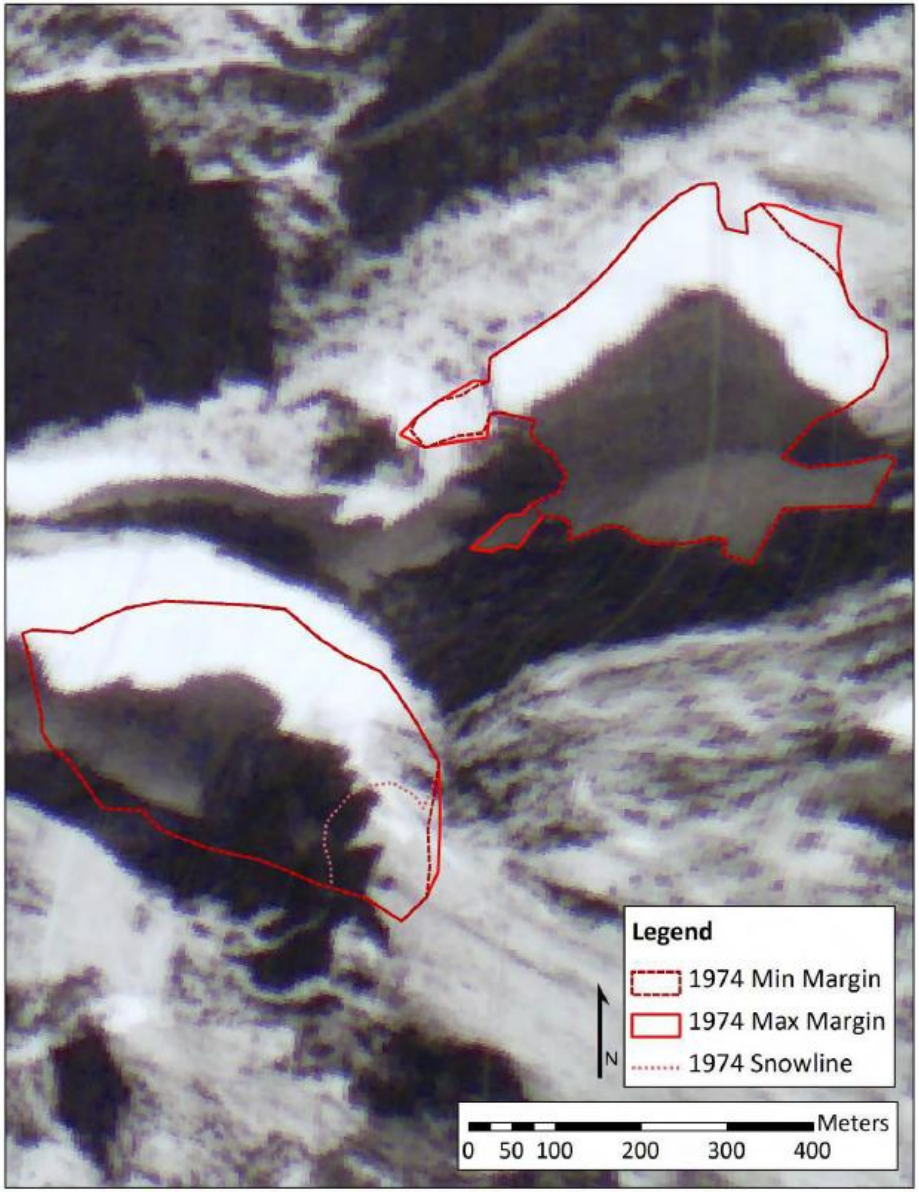


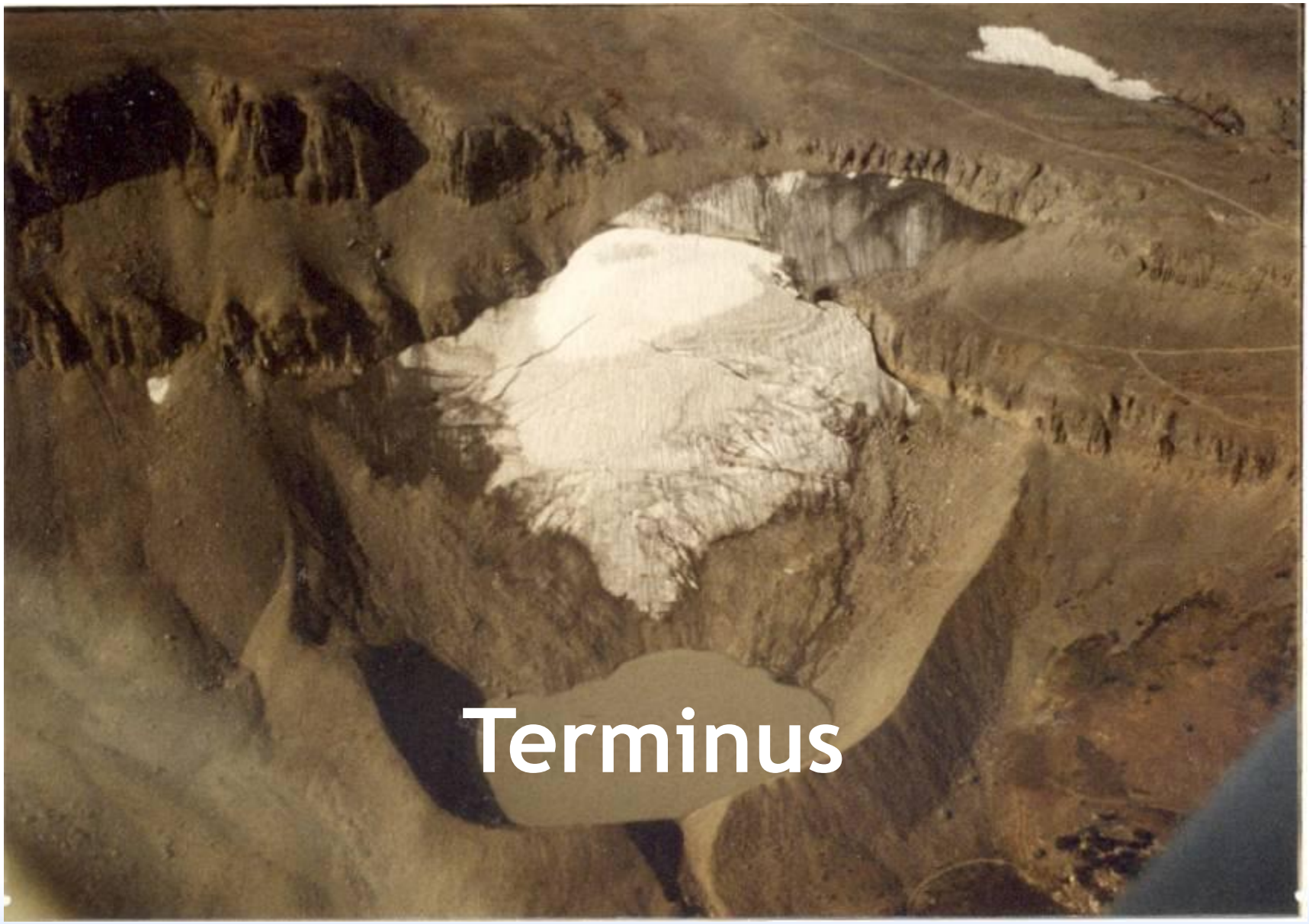
Figure 17. Skillet Glacier in 1974.

From Reynolds (2011), Recent Fluctuations in Grand Teton National Park, Wyoming, Masters Thesis, ISU.

Falling Ice Glacier, Mt. Moran

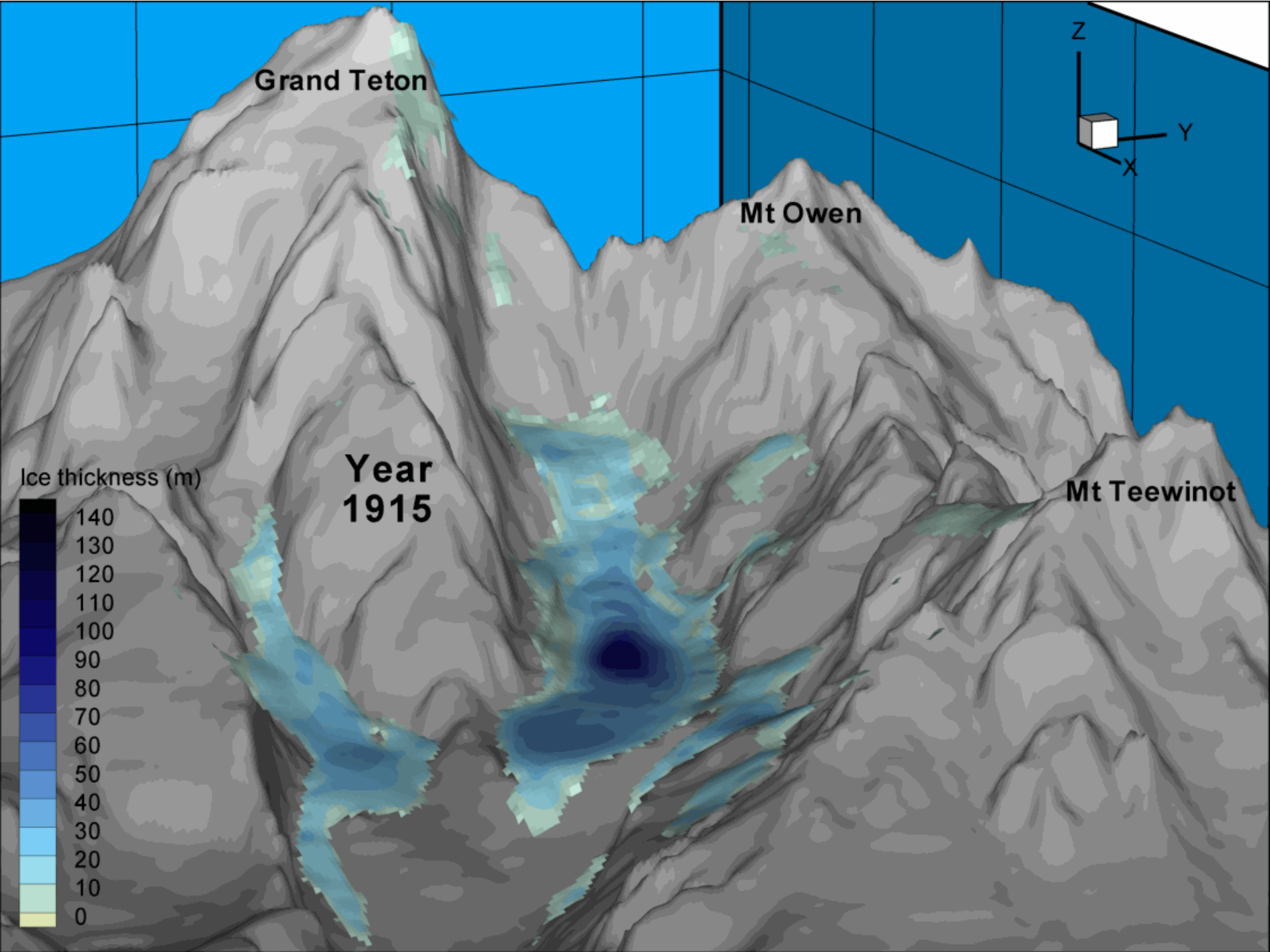
Conclusions

- Modeling experiments suggest that a temperature increase of ~1.5°C would dramatically reduce the volume of the Teton glacier
- At late 20th century global warming rates (~0.1°C / decade), such retreat could take as long as 150 – 200 years
- Global climate models scaled to the Pacific NW project an increase in average temperature on the order of 0.2°-0.6°C (0.3°-1°F) per decade throughout the 21st century, implying a much faster recession.
- The mass balance profile of small alpine glaciers is often very steep near the equilibrium line altitude, suggesting decreased sensitivity relative to larger, more exposed, glaciers.
  - Future simulation efforts are aimed at improving resolution of model, in order to measure sensitivity of small alpine glaciers as they recede into increasingly shaded environments.



Idaho National Laboratory

Photo by Ed Williams, BYU Idaho


Grand Teton
Mt Owen
Mt Teewinot
Year
1915
Ice thickness (m)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Z
Y
X

Questions

- Barring ‘local’ redistribution of snow by wind, avalanching etc, how variable is precipitation across short distances in the mountains and how would one capture that in a simple model?
- In paleoglacier modeling,
  - How is a large change in mountain precipitation distributed vertically?
  - How reasonable is it to assume constant lapse rates?
    - Are pseudo-vertical lapse rates related to vertical precipitation gradients?
- Need more data to describe mountain climate and its variability